Experimental and Numerical Assessment of Crash Behavior of Welded Thin Wall Rectangular Steel Sections

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***Abstract*—The crash behavior of Cold Rolled Mild Steel (CRMS) closed form thin section produced by stitch welding at periodic intervals of length was studied by conducting axial compressive tests at loading velocities of 5 mm/min and 6000 mm/min. The deformation shape, peak forces and energy absorption capacity of the sections estimated numerically showed a good correlation with the experimental data.**

***Index Terms* — axial crushing, energy absorption, peak force, welded joints, cut slot.**

I. INTRODUCTION

Welding is the primary method of joining employed in the car industry for structural construction work. Quite often, due to limitations in manufacturing of closed form sections, thin sheets/plates are bent to form a closed form section and are seam welded (continuous welding) or stitch welded (welding at periodic intervals of section). When such welded structural members are subjected to high velocity impact, such as in the case of a crash, the deformation behavior is very different from conventional closed form sections. The purpose of this study is to evaluate the crash behavior of stitch welded closed from sections. The crash performance at two different velocities of impact are evaluated numerically and validated through experiments. Crash behavior differs from conventional quasi-static compression behavior of material in view of dynamic buckling. The speed at which the plastic waves propagate in a material becomes one of the major parameters in determining the type of buckling. Progressive buckling, typical of crash, can occur only when the applied axial compressive load is higher than the yield stress of the material. During crash, the main energy dissipating mechanisms are plastic deformation and fracture or tearing. A vehicle's crash performance depends on the weld structural integrity, peak force, mean effective crushing force and energy absorbing capacity of the structure. As passenger safety is closely related to peak force, keeping the minimum peak force and maximum energy absorption capacity of the compartment frame are desirable. The displacement of the space frame should be such that there will not be any intrusion into passenger compartment. Strain rate, also expressed as deformation rate plays an important role in the determination of load carrying capacity and energy absorption capacity of structural members.

II. EXPERIMENTAL EVALUATION OF MATERIAL PROPERTIES

Numerical simulation of crash behavior requires input on material stress-strain properties at high strain rates. This was obtained by conducting tensile tests on base material at different rates of loading.

A. Tensile Test Specimen Specification

Four specimens made of cold rolled mild steel of thin section were prepared as per ASTM E-08 standards (Fig. 1). Tensile tests were carried out on a 100 kN- MTS servo hydraulic material test system at the loading velocities of 5, 100, 500, and 1000 mm/min. at room temperature.

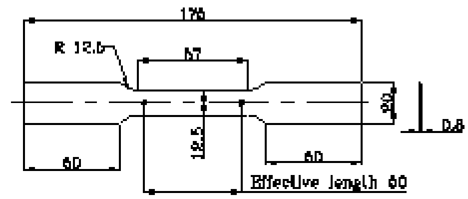

Figure 1 Monotonic test specimen drawing (ASTM E 8/E 8M – 08)

From the tensile test, tensile load and the corresponding displacement data were extracted to plot the engineering stress- strain curves as shown in Fig. 2. The required material properties such as, tangent modulus, young's modulus and yield stress were obtained from the stress strain curve and fed into the numerical simulation.

B. Strain rate hardening

The uniaxial stress-strain behavior of the material was fitted to the Cowper-Symonds equation (1) which gives the strain rate hardening effect, Cowper Symonds coefficients and Cowper Symonds exponent.

Cowper-Symonds equation:

$$\frac{\sigma^0{}_d}{\sigma} = 1 + \left(\frac{\dot{\varepsilon}}{D}\right)^{1/q} \quad ; \sigma_d{}^0 \geq \sigma \qquad (1)$$

Where

$\sigma_d{}^o$ Dynamic flow stress at uniaxial plastic strain rate.

$\dot{\varepsilon}$ Strain rate

σ Associative static flow stress

D Cowper-Symonds coefficient

q Cowper-Symonds exponent

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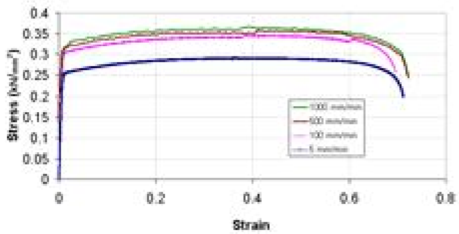

Figure 2. Engineering stress - strain curve at various strain rate.

The parameter "q" is the slope of straight line and the intercept on ordinate is "log D". The Cowper – Symonds parameters were determined from the graph shown in Fig. 3 and the values are tabulated in Table 1

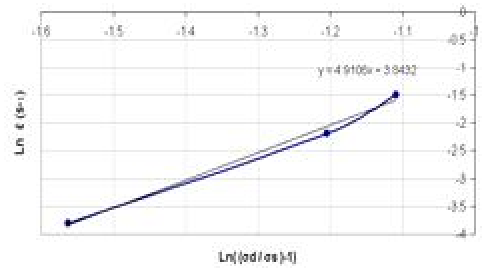

Figure 3 Cowper - Symonds parameters

TABLE I
COWPER – SYMONDS PARAMETERS

D	q
46.67 s^{-1}	4.9

III. EXPERIMENTAL CRASH TESTS

A. Specimen preparation

Commercially available thin walled rectangular cross section of CR mild steel having thickness of 0.8 mm was cut to the length of 140 mm. A slot of 2 mm width was cut longitudinally on one side of the specimen for the entire length to simulate the open section, which is typically obtained when CR sheets are bent multiple times to obtain a closed form section. The cut slot has been joined for every 20 mm using TIG weld and 20 mm has been left open. Figure 4 and 5 shows the details of thin walled sections.

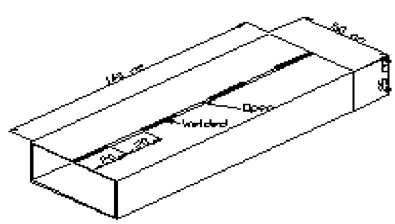

Figure 4. Detail of the drawing specification

Figure 5. Specification of welded joint with cut slot

B. Compression test

The rectangular thin walled specimen was kept in between the compression platens of the test system. During the test, the top platen was kept rigid and the bottom platen which has mounted onto the actuator was moved upwards with the aforementioned velocities to a pre-determined distance of 50 mm of compression. The upward movement of the actuator makes the specimen to buckle within the compression length of 50 mm. The buckled samples are shown in Fig. 6 and Fig. 7.

Figure 6. Deformed shape of the specimen at 5 mm/min

Figure 7. Deformed shape of the specimen at 6000 mm/min

IV. NUMERICAL SIMULATION OF CRASH TEST

The buckling characteristics of thin walled rectangular welded section have been determined numerically using LS DYNA Explicit Solver. The geometry of the specimen was modeled using shell 163 element with 5 integration points. The contact Belystschko shell element and rigid block were defined using "Automatic Single Surface Contact" (ASSC), and a coefficient of friction of 0.25 was assumed to avoid lateral movements. The normal force at failure of 157.8 MPa and shear force at failure of 37.6 MPa were assumed as an input data. The meshed model with welding nodes is shown in Fig. 8. Cowper Symonds equation parameters for CR Mild Steel thin walled specimens shown in Table 1 were fed as input parameters for the numerical analysis.

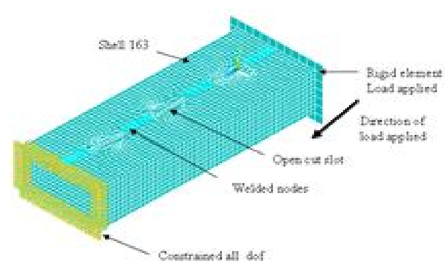

Figure 8. Meshed weld model with boundary conditions.

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The numerical simulations corresponding to the loading velocity of 5 mm/min and 6000 mm/min were obtained for the time period of 600 s and 0.5 s respectively. The dimensions of the shell element are length = 140 mm, width = 50 mm, height = 25 mm, thickness = 0.8 mm, Young's modulus = 192 GPa and density = 7800 kg/m^3. The compressive deformed shapes of the model are shown in Fig. 9 and Fig. 10.

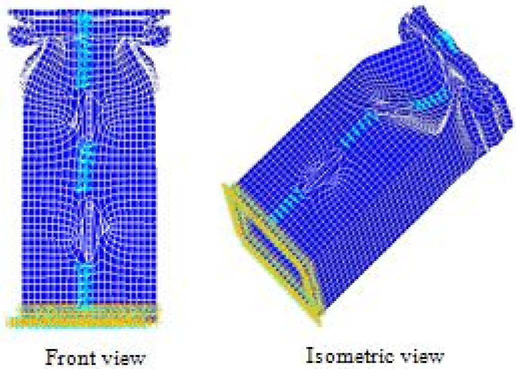

Figure 9. Deformed shape of the model at 5 mm/min

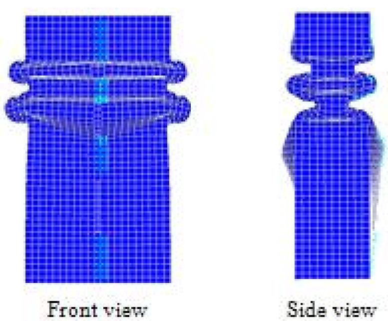

Figure 10. Deformed shape of the model at 6000 mm/min

V. COMPARISON OF AXIAL COMPRESSION TEST RESULTS

From the compression test readings of each samples and numerical results, peak force and maximum energy absorbed by the samples were calculated. The corresponding load vs. displacement graphs are plotted as shown in Fig. 11 and Fig. 12 and their energy absorption capacity were plotted in Fig. 13 and Fig. 14.

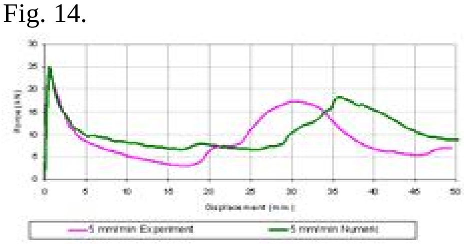

Figure 11. Force vs. Displacement plots at the velocity of 5 mm/min

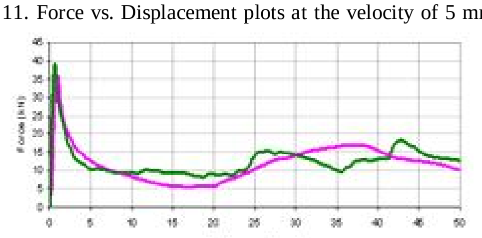

Figure 12. Force vs. Displacement plots at the velocity of 6000 mm/min

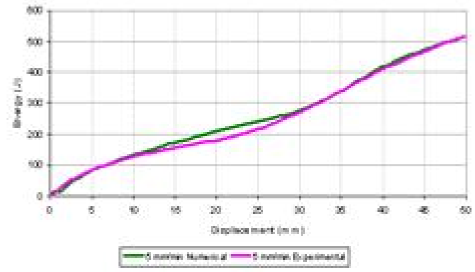

Figure 13. Energy vs. Displacement plot at the velocity of 5 mm/min

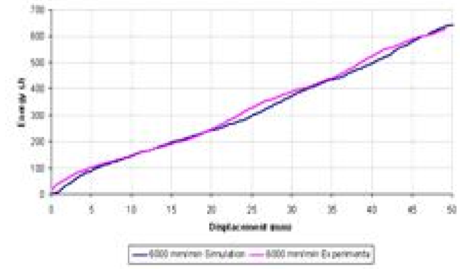

Figure 14. Energy vs. Displacement plots at the velocity of 6000 mm/min

The entire load – displacement curves show higher compressive repulsive force when the first fold is formed and subsequent folding is formed under smaller repulsive force. The symmetric mode behavior of the thin walled section is associated with the formation of lobes.

TABLE II
DEFORMED COMPRESSION TEST RESULTS AT 5 MM/MIN

Loading Velocities	Peak force (kN)	Mean crash force (kN)	Energy absorbed (J)
Exp. results	23.37	10.35	517.13
Simulation results	24.57	10.43	528.35

TABLE III
DEFORMED COMPRESSION TEST RESULTS AT 6000 MM/MIN

Loading Velocities	Peak force (kN)	Mean crash force (kN)	Energy absorbed (J)
Exp. results	35.72	12.49	624.60
Simulation results	34.13	13.28	664.03

DISCUSSION

The crash characteristics of the thin walled rectangular cross section has been determined experimentally and validated numerically. Under the static and dynamic loading, two side walls were protruded in one folding and other two walls recessed on the next folding. It clearly shows that the lobes deform in the same manner having symmetric mode as shown in Fig. 9 and Fig. 10. During buckling, no crack and no fracture was observed. It was observed that due to increase in strain rate, the energy absorption by the welded section was calculated as 517.13 J and 624.6 J at the velocity rate of 5 mm/min and 6000 mm/min respectively (Table 2 and 3). Figures 11 and 12 show the peak loads and shape of the curves gives good correlation with the experimental results. Figures 13 and 14 show the comparison between the simulation and experimental results of energy vs. displacement curve.

CONCLUSIONS

The experimental crash behavior of CR mild steel welded joint shows good correlation with numerical results in terms of energy absorption capacity and peak force. Thus the numerical method can effectively be used to estimate the crash characteristics prior to conducting the actual compressive tests. The strain rate affects the hardening behavior of material which in turn affects the peak force as well as energy absorbing characteristics. Based on the experimental results, it is established that size of the lobe and distance between the lobes varies if the strain rate increases. Further studies are required to study the energy absorption capacity in the actual crash events at the strain rate of 10^3 s^{-1} to 10^5 s^{-1}.

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